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# AUTOMATIC REBALANCING OF RADIAL GATES OF THE SPILLWAY DAM IN CAMEROON

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***ABSTRACT***

***One of the problems facing hydroelectric plants is the imbalance of radial gates of the spillway dam. This imbalance causes the deterioration of lateral guiding seals, the deterioration of thermal relays, the deterioration of motors, the rupture of chains and the deformation of radial gates slides. This results in higher maintenance costs. The most frequently used method for rebalancing is the manual method, acting on the brakes. It is not effective in the sense that it waits for the adverse effects of imbalance to occur before it is started and is very limited. In order to avoid the harmful effects of the imbalance of radial gates, where each bank is controlled by a mechanical winch, we have set up a methodology for their automatic rebalancing. The steps of the automatic methodology are; the determination of the maximum permissible unbalance, the determination of the pulse generation frequency for the choice of the input module type of the PLC (fast input or not), the determination of the relation between the number of pulses generated by the encoder and the vertical position on each side of the gate. The results obtained after application in the case of a spillway dam in Cameroon are as follows: the maximum allowable imbalance is is*** $\mathbf{0.052\,m}$***, the frequency of generation of pulses by the encoder is*** $\mathbf{3.18\,Hz}$***. Hence the determination of relationships*** $\boldsymbol{h_B = 0.005\,N'_{imp}}$***during the ascending phase and*** $\boldsymbol{h_B = h'_B - 0.005\,N'_{imp}}$ ***during the descending phase, with the number of pulses generated by the encoder (***$\boldsymbol{N_{imp}}$***) of the left bank and the vertical position of the left and right side of the radial gate.***

***KEYWORDS: Hydroelectric Plants, Programmable Automaton, Radial Gates, Rebalancing & Spillway Dam***

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## 1. INTRODUCTION

Cameroon has several hydroelectric dams [1] [2]. In order to regulate turbined water and to prevent the flooding of hydroelectric power plants, the latter are equipped with spillway dams. Spillways have large adjustable openings that take different names according to their configurations. When these valves are controlled by two winches arranged on each side, the problem of imbalance of the valve is likely to arise during its operation. The spillway with this configuration in Cameroon has as main failure the imbalance of radial gates during their maneuvering. Two methods can be used to rebalance the structure; the manual method and the automatic method. The manual method is the one generally used, although it is not effective [3]. The manual method is done by acting on the brakes of the left and right winch, by loosening the brakes from one bank to the other while observing the sagging of the gate under the effect of its weight, up to where it is clear to the eye that it is balanced. This way of doing things has limits; rebalancing is not optimal since it is done with the naked eye, requires several people to do

it, requires effort to release the brakes, is too tedious, it is put in place once the adverse effects of the imbalance are present. The purpose of this study is to set up a methodology, an approach for the implementation of the automatic method. In the following lines, we will present the valve with its accessories in the material section. We will develop the methodology for the implementation of the automatic rebalancing in the method section and finally in the last section, we will present and discuss the results.

## 2. EQUIPMENT

### 2.1 Working Principle of the Radial Gate

When the opening command is given on the control panel (or Closing), the asynchronous motor 1 transmits the movement to the gearbox 3. The movement of 4 will be transmitted to the intermediate shaft 5 and then to the upper gear 10, which will cause the chain 9 to move. The chain meshes with the lower gear 17, which is recessed on the segment of the valve, the chain 9 continues its course on the guide pinion 18 embedded in the wall and ends on the segment valve where one of its ends is recessed. On the side face 16 are mounted the seals which allow the valve to move on the slide 15. The valve sliding on 15, the arms 14 rotate relative to the x axis, the center of this pivot is located in the pillar 7. The other end of the chain is located after the upper pinion in the chain garage 8. The maximum opening to the design of the segment valve is 14 m. Figure 1 shows the block diagram of a radial gate. Figure 2 shows the position of the segment valve (in section) when closed [3].

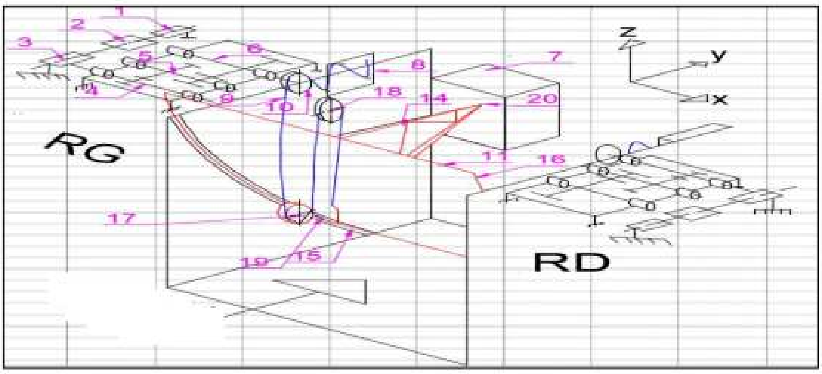


**Figure 1: Functional Scheme of a Radial Gate**

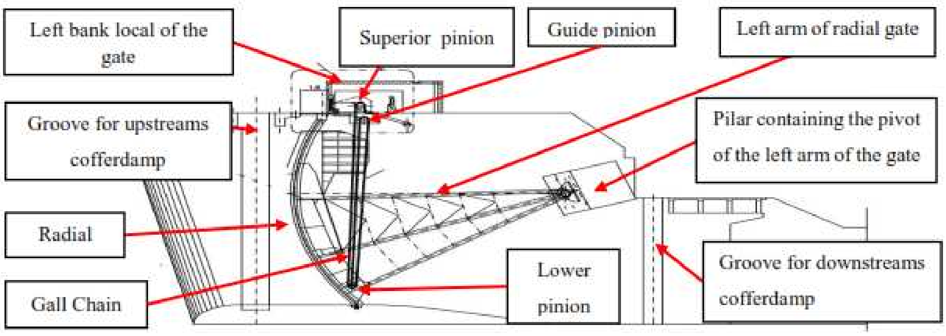


**Figure 2: Sectional View of a Pass with the Closed Radial Gate**

Figure 3 below shows the geometric model of an unbalanced radial gate.

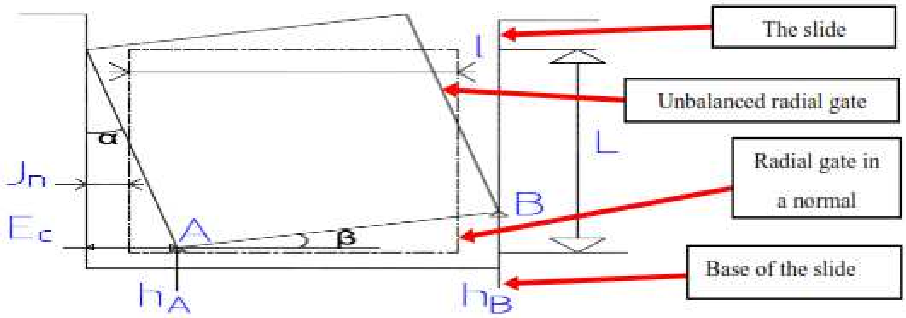


**Figure 3: Geometric Model of Imbalance, Worst Case**

Where; $L$ (in m) representing the height of the gate ; $Jn$ (in m) representing the normal clearance between the slide and the gate ;$l$ (in m) representing the width of the gate; $E_c$ (in m) representing the clearance between the slide and the gate at the working state; $h_A$, (in m) representing the height of point A situated at the base of the gate (left side); $h_B$, (in m) representing the height of point B situated at the base of the gate (right side); $\alpha = \beta$, angle of deflection.

Figure 4 below shows the schematization of the transmission of motion between the intermediate shaft and the main shaft of a winch of the radial gate found at a damp in Cameroon.

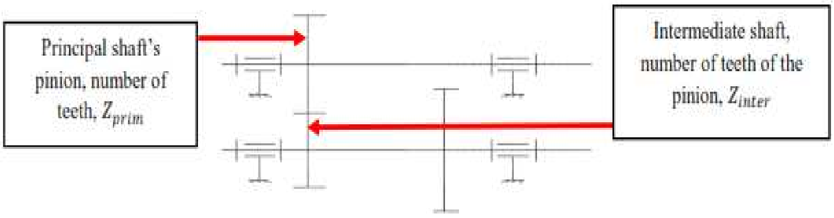


**Figure 4: Schematization of the Gear System between the Intermediate Shaft and the Principal Shaft**

Figure 5 below shows the modelling of the motion transmission between the encoder shaft and the intermediate shaft of the winch of the radial gate found at a spillway dam in Cameroon [4]. The programmable logic controller used for the implementation of the code lines [5] [6] of the program is a PLC of the SCHNEIDER type. Figure 6 below shows the mounting of the modules on the rack.

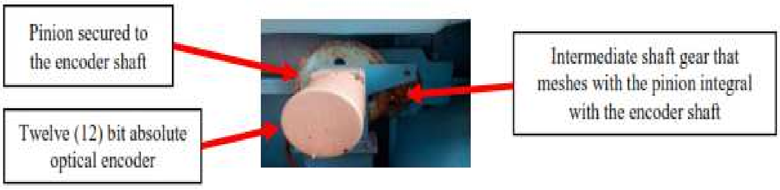


**Figure 5: Characteristics of the Encoder and Relation with the Intermediate Shaft**

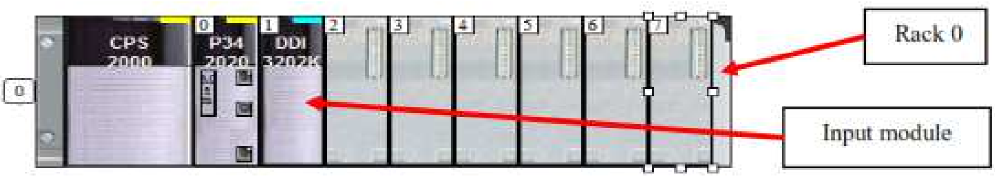


**Figure 6: Mounting of the Modules on the Rack**

## 2.2 Displayed Interfaces

### Degraded Operating Mode

The degraded operating mode is a mode where the programmable controller corrects the unbalance fault according to the program that has been given to it. When the height difference exceeds the maximum allowable height: the valve will come to a standstill, the synchronism separation contactor of the bank of the lowest segment will open, the closure of the valve will be initiated by the PLC, the segment will go down until the difference is almost zero and less than the maximum permissible height, the open synchronism separation contactor will close, the phase preceding the unbalance will be active, i. e. if the segment was going down just before the imbalance, it will continue to go down. However, if the segment was going up just before the imbalance, it will continue to rise.

## 3. METHOD

The automatic method is done by the PLC with a written program using synchronism separation contactors between the left and right bank. The implementation of this method is done following the diagram shown in figure 7 below.

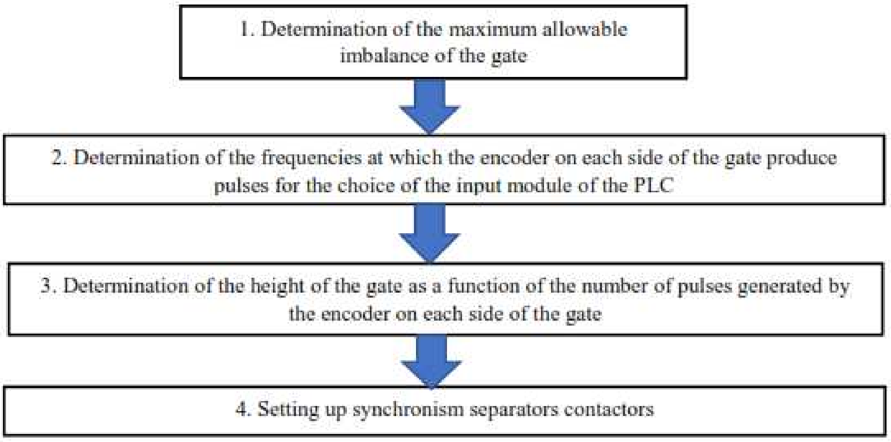


**Figure 7: Automatic Method Diagram**

The parameters below must be calculated.

### 3.1 Determination of the Maximum Allowable Imbalance, $\Delta h_{max-allowable}$

Maximal imbalance occurs when[3] :

$E_c - J_n = J_n$

$\sin(\alpha) = \frac{E_c}{L}$ *and* $\sin(\beta) = \frac{\Delta h}{l}$ *with* $\Delta h = h_B - h_A$

$$\Delta h = h_B - h_A \qquad (1)$$

$\Delta h$ (in m) shown in equation (2) above, representing the offset in height between the left and right side of the gate

But

$\alpha = \beta \Rightarrow \frac{E_c}{L} = \frac{\Delta h}{l}$

$$\Delta h = l\frac{E_c}{L} \tag{2}$$

When $\Delta h$ is max, $E_c$equals $2J_n$. According to equation (2) above, we have;$\Delta h_{max} = 2l\frac{J_n}{L}$

As a security measure we will adopt as maximum reachable 80% of actual maximum valueas shown in equation (3) below [3].

$$\Delta h_{max-allowable} = 1.6l\frac{J_n}{L} \tag{3}$$

### 3.2 Calculation of the Frequencies at which Pulses must be Generated for the Choice of an Encoder

By definition, the frequency at which the encoder generates pulses is given by the equations (4) and (5) below, where: $f_i = n_p\omega_{\text{encoder}}$

$$\frac{\omega_{inter}}{\omega_{\text{encoder}}} = \frac{Z_{\text{encoder}}}{Z'_{inter}} \Rightarrow \omega_{\text{encoder}} = Z'_{inter}\frac{\omega_{inter}}{Z_{\text{encoder}}} \tag{4}$$

$$f_i = n_p Z'_{inter}\frac{\omega_{inter}}{Z_{\text{encoder}}} \tag{5}$$

Where, *fi* (in Hz) representing the frequency at which pulses are generated by the encoder, $Z_{encoder}$ representing the number of teeth of the pinion of the encoder, $w_{encoder}$ representing the speed of the shaft of the encoder, $w_{inter}$representing the speed of the intermediate shaft, $n_p$ representing the number of positions of turns equal to $2^{12}$. We must therefore choose an input module having a frequency of scanning of its inputs greater than or equal to the frequency of generation of the pulses.

### 3.3 Determination of the Relationship between the Number of Pulses Generated by the Encoders (on Either Side of the Gate) and the Vertical Position of Each Side of the Gate

In order to determine that relationship, let $N_{imp}$represent the number of pulses generated by an encoder at any time *t* in the ascending phase of the gate.

If $2^{12}$ pulses correspond to 1 turn of the encoder

1 pulse will correspond to $\frac{1}{2^{12}}$ turn of the encoder

The number of revolution done by the shaft of the encoder, $N_c$as a function of the number of pulses generated, $N_{imp}$is:

$$N_c = \frac{N_{imp}}{2^{12}}$$

Equation (4) can be rewritten as:

$$N_{inter} = N_c\frac{Z_{\text{encoder}}}{Z'_{inter}}$$

Concerning the gear system between the intermediate and principal shaft (figure 4) we have:

$$N_{prim} = N_{inter}\frac{Z_{inter}}{Z_{prim}}$$

$$N_{prim} = N_c \frac{Z_{\text{encoder}}}{Z'_{inter}} \frac{Z_{inter}}{Z_{prim}}$$

Knowing that a complete revolution of the upper gear, that mounted on the main shaft causes the valve to rise a vertical distance of $2\pi r_{prim}$ (with $r_{prim}$ representing the radius of primitive circle of the superior gear).

We determine equation (6) below as follow: $h_A = \frac{N_{prim}}{2\pi r_{prim}}$

$$h_A = N_c \frac{Z_{\text{encoder}}}{Z'_{inter}} \frac{Z_{inter}}{Z_{prim}} \frac{1}{2\pi\, r_{prim}}$$

$$h_A = \frac{N_{imp}}{2^{12}} \frac{Z_{\text{encoder}}}{Z'_{inter}} \frac{Z_{inter}}{Z_{prim}} \frac{1}{2\pi r_{prim}} \quad (6)$$

In the descending phase we have: $\boxed{h_A = h'_A - 0.005\, N_{imp}}$

Where $h'_A$ representing the maximum height reached by point A in the ascending phase of the gate and $N_{imp}$ represent the number of pulses generated during the descending phase.

The motion transmission between the intermediate shaft and the right bank encoder (on the B side) is identical to that between the intermediate shaft and the left bank encoder (on the A side).

Applying the same reasoning we have the equation (7) below.

In the ascending phase we have:

$$h_B = \frac{N'_{imp}}{2^{12}} \frac{Z_{\text{encoder}}}{Z'_{inter}} \frac{Z_{inter}}{Z_{prim}} \frac{1}{2\pi\, r_{prim}} \quad (7)$$

Where $N'_{imp}$ representing the number of pulses generated by the encoder associated with point B

In the descending phase, we have the equation (8) below:

$$\boxed{h_B = h'_B - 0.005\, N_{imp}} \quad (8)$$

Where $h'_B$ representing the maximal height reached by point B in the ascending phase of the gate and $N_{imp}$ represent the number of pulses generated in the descending phase at any time.

### 3.4 Setting up Synchronism Separation Contactors

Synchronism separation contactors allow the activation of the motor of one bank while stopping those on the other bank.

## 4. RESULTS

Here, we will present the results obtained, the data and equations used to obtain those results.

**Data**

Tables 1 and 2 shows the characteristics of the motion transmission between the encoder shaft and the principal shaft with the countershaft which will be used to calculate the pulse generation frequency and the relationship between the number of pulses generated by the encoder and the position of the gate.

**Table 1: Characteristics of the Gear System between the Encoder Shaft and the Intermediate Shaft**

| | |
|---|---|
| **Pinion of the intermediate shaft** | Number of teeth $Z'_{inter}$= 24 |
| **Pinion of the encoder** | Number of teeth , $Z_{encoder}$ = 108 |
| **Speed of the intermediate shaft, $\boldsymbol{\omega_{inter}}$** | $w_{inter} = 0.0025888 \frac{rev}{s}$ |

**Table 2: Characteristics of the Gear System between the Intermediate Shaft and the Principal Shaft**

| | |
|---|---|
| **Principal Shaft** | Number of teeth, $\boldsymbol{Z_{prin} = 80}$, radius of primitive circle, $\boldsymbol{r_{prim} = 103mm}$ |
| **Pinion of the intermediate shaft** | Numberof teeth, $Z_{inter} = 20$, |
| **Speed of the intermediate shaft, $\boldsymbol{\omega_{inter}}$** | $w_{inter} = 0.0025888 \frac{rev}{s}$ |

Table 3 presents the characteristics of the radial gate which will make it possible to calculate the maximum allowable unbalance.

**Table 3: Characteristics of the Radial Gate of the Spillway Dam Found in Cameroon [3]**

| Length, L | Width, l | Jn, Normal Clearance between the Slide and the Gate | Weight |
|---|---|---|---|
| **17.25 m** | 14 m | 40 mm | 174 tonnes |

**Results Obtained**

**Maximal Allowable Imbalance, $\Delta h_{max-allowable}$**

Using equation (3) and Table 3, we have:$\Delta h_{max-allowable} = 1.6 * 14 * \frac{0.04}{17.25}$

$\boxed{\Delta h_{max-allowable} = 0.052\ m}$

**Pulse Generation Frequency for Encoder Selection**

Using equation (5) and Table 1 we have:$f_i = 2^{12} * 24 * \frac{0.0025888}{80}$

$\boxed{f_i = 3.18\ Hz}$

**Relation between the Number of Pulses Emitted by the Encoders of Each Bank and the Position (Height of the Valve)**

Using equation (6), Tables 1, 2 and 3we have:$\boxed{h_A = 0.005\ N_{imp}}$ (9)

In the descending phase:$\boxed{h_A = h'_A - 0.005\ N_{imp}}$ (10)

The vertical position of the left side of the gate as a function of the number of pulses generated by the encoder placed on the left winch during the raising and lowering of the gate is given by the equations (9) and (10) respectively.

Using equation (8), we have $\boxed{h_B = 0.005\ N'_{imp}}$ (11)

In the descending phase, we have:$\boxed{h_B = h'_B - 0.005\ N'_{imp}}$ (12)

The vertical position of the right side of the gate as a function of the number of pulses generated by the encoder placed on the right winch during the raising and lowering of the gate is given by the equations (11) and (12) respectively. The results of the automatic method are visible in the field and also on the display interface of the PLC used. These interfaces are presented below. Imbalance can happen in two cases.

- **Case 1:** The height of the left bank of the segment is greater than that of the right.

Figure 8 shows the interface displayed in this case. The absence of the right bank motor and the red coloring of this zone indicate the opening of the right bank synchronization separation switch.

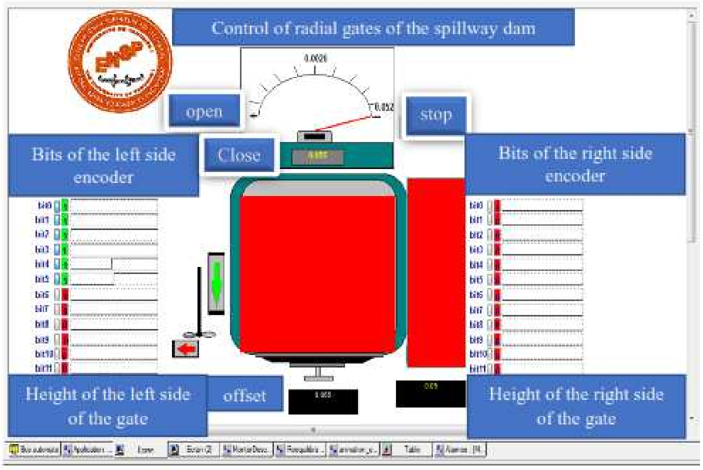


**Figure 8: Interface Displayed for Case 1**

The difference of 0.052 m calculated by the automat on applying equation (1) indicated by the needle in this case is greater than the maximum allowable deviation 0.05 m given by equation (3).

- **Case 2:** the height of the right bank of the segment is greater than that of the left

### 4.1 Opening Interface of the Radial Gate

When the operator gives the order to mount or open the valve, the interface shown in Figure 9 below appears on the HMI. Arrow indicating that the segment is rising (the valve opens), the evacuated water level increases.

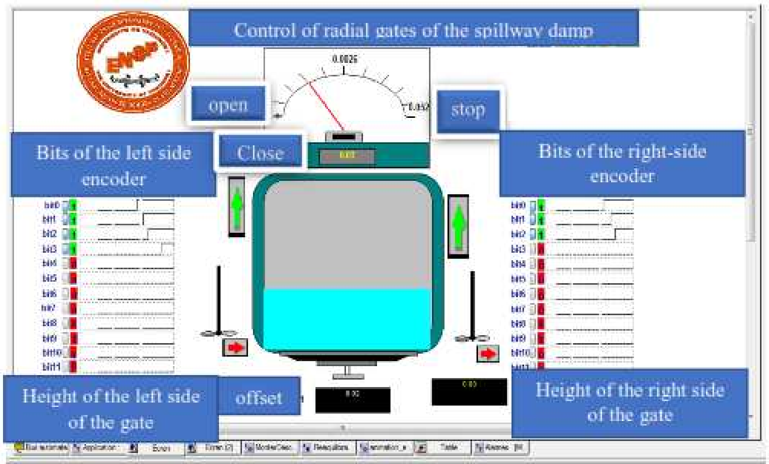


**Figure 9: Opening Interface of the Radial Gate**

Needle indicating the difference of 0.02 m. The deviation calculated by the automaton applying equation (1) indicated by the needle in this case is greater than the maximum permissible deviation given by equation (3).

This interface indicates:

- The current output status of the optical encoders;
- The height of the left bank (in meters) of the segment in relation to the slab;
- The height of the right bank of the segment in relation to the slab;
- The gap between the right bank and the left bank of the segment;
- The direction of rotation of the engines on each bank;
- The valve open (i. e. the segment is going up).

**4.2 Interface after Rebalancing the Radial Gates**

Two interfaces are engageable depending on whether the valve was opening or closing just before rebalancing occurred. In the event that the valve closes, the interface shows in figure 10 below will be displayed with the gap set to zero. Arrow indicating that the segment is going down (the valve is closing), the water level is going down.

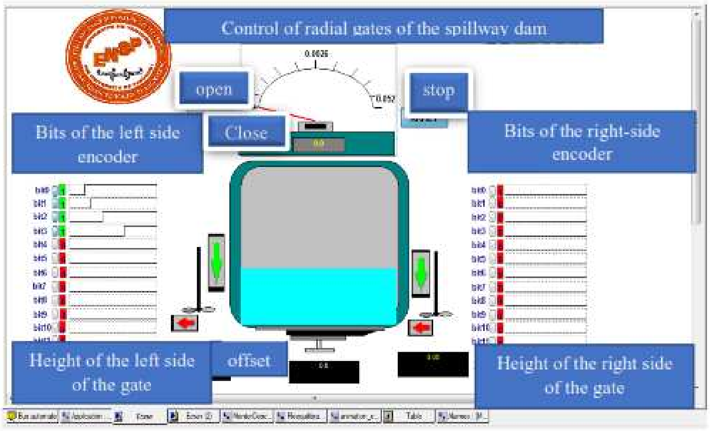


**Figure 10: Interface Displayed after Rebalancing Automatically the Gate**

Motor rotation direction during the climb phase.

This interface indicates:

- The current state of optical encoder outputs;
- The height of the left bank (in meters) of the segment in relation to the slab;
- The height of the right bank of the segment in relation to the slab;
- The gap between the right bank and the left bank of the segment;
- The direction of rotation of the engines on each bank;
- Closing the valve (i. e. the segment is descending).

## 5. CONCLUSIONS

The problem dealt with in this paper is the imbalance of the flap valves of the spillway dam. We presented the two different methods that contribute to their rebalancing; the manual method and the automatic method. The manual method has as its field of action the electro-hydraulic brakes of the winches on the left and right side of the valves. The automatic method is carried out by a programmable automaton, which rebalances the structure according to the program which has been given to it. The maximum allowable imbalance, $0.052\ m$, the frequency of generation of pulses by the encoder, $3.18\ Hz$ . The automatic method prevents the harmful effects of the imbalance of radial gates to occur.

***REFERENCES***


1. *MINEE, (2006). Assistance au ministère de l'énergie et de l'eau dans l'élaboration du plan de developpement à long terme du secteur de l'électricité horizon 2030, volume 4.*
2. *NGUEMADJEUK M., (2017). Amélioration du système de refroidissement des paliers alternateurs des groupes turboalternateurs de la centrale hydroélectrique de Songloulou. Mémoire de fin d'étude d'ingénieur en Génie Mécanique, ENSP Yaoundé, Cameroun, 136p.*
3. *TSOPMO T. J., (2018). Contribution au rééquilibrage des vannes segments à clapets du barrage évacuateurs de crues du barrage hydroélectric de Songloulou. Mémoire de fin d'étude d'ingénieur en Génie Mécanique, ENSP Yaoundé, Cameroun, 126p.*
4. *ENEO Cameroun SA. le barrage hydroélectrique de Songloulou [En ligne]. Disponilbe sur Internet: https://eneocameroon.cm/index.php/fr/production/nos-sites-de-production/nos-siteshydroelectrique-de-songloulou.*
5. *SILANUS M. Les codeurs optiques [En ligne]. [Consultée le 01.06.2018]. Disponible sur Internet : http://silanus.fr/bts/activites/Maugenet/co/Les_codeurs_optiques_1.html.*
6. *Equipe SII : CPGE Lycée J. Garnier. Capteur-Actionneur: technologie [En ligne]. [Consultée le 01.06.2018]. Disponible sur Internet*

   *:http://stephane.genouel.free.fr/FT/0%20Dossier%20technique/1%20Texte/Scenari%20capteurs/co/module_DT_17.html.*